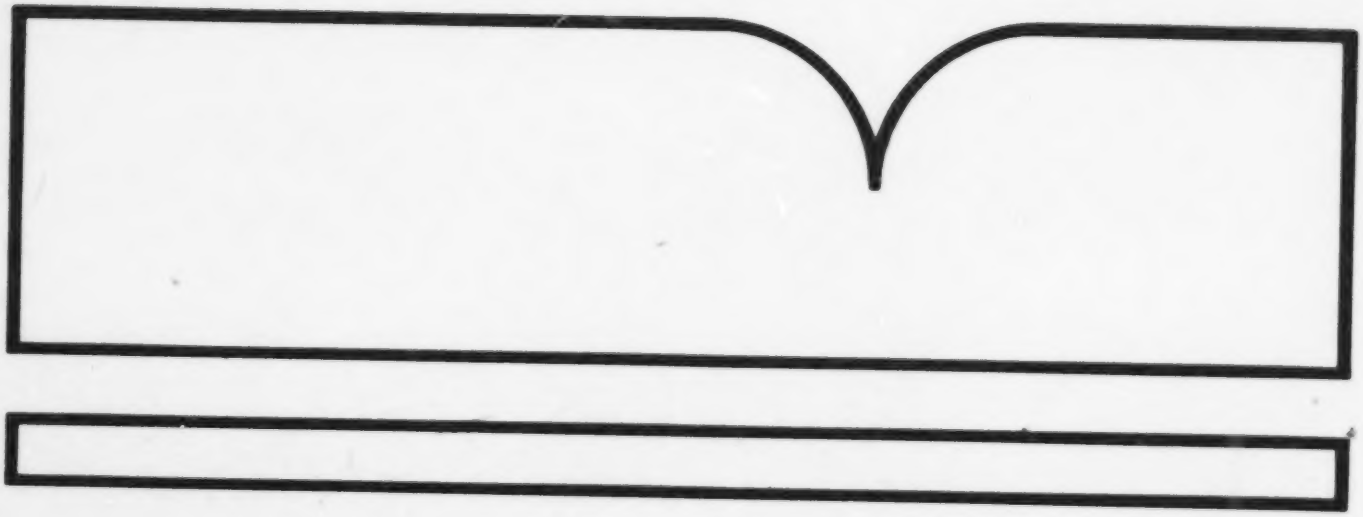
PB81-213142

The Behavior of Asbestos-Cement Pipe Under Various Water Quality Conditions A Progress Report

(U.S.) Environmental Protection Agency
Cincinnati, OH

1980



U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before comple

1. REPORT NO. EPA-600/J-80-285	2. Journal Article	3. PB81-213142
4. TITLE AND SUBTITLE The Behavior of Asbestos-Cement Pipe under Various Water Quality Conditions: A Progress Report		5. REPORT DATE May 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.W.Buelow, J.R.Millette, E.F.McFarren, J.M.Symons		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. EPA 26 W. St. Clair St. Cincinnati, Ohio 45268		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same as box 9		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
Published in: Journal AWWA 72(2):91-102(Feb 1980)

16. ABSTRACT
Asbestos-cement pipe has had a reputation for resisting attack by aggressive waters that cause corrosion of metal pipe materials. The results of this study suggest that asbestos-cement pipe behaves much like other piping materials, except PVC, that are commonly used for potable water distribution.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

PRODUCT OF:
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

(27)

RESEARCH AND TECHNOLOGY

EPA-600/J-80-285
Journal Article

The Behavior of Asbestos–Cement Pipe Under Various Water Quality Conditions: A Progress Report

Ralph W. Buelow, James R. Millette, Earl F. McFarren, and James M. Symons

Asbestos–cement pipe has had a reputation for resisting attack by aggressive waters that cause corrosion of metal pipe materials. The results of this study suggest that asbestos–cement pipe behaves much like other piping materials, except PVC, that are commonly used for potable water distribution.

In response to concern over the potential problem of asbestos fiber release from the walls of asbestos-cement (A-C) pipe, the American Water Works Association Research Foundation reviewed the issue of asbestos in water, specifically in relation to the use of asbestos-cement pipe. A committee of six experts in the field was convened, and their report was published as part 2 of the September 1974 JOURNAL AWWA. Appendix F of that report contained eleven research needs related to the question, "Does the use of asbestos-cement pipe in potable water systems pose a health hazard?"

Approach

In response to this call for research, several projects were designed to determine whether A-C pipe would be attacked and asbestos fibers would be released from the pipe under various water quality conditions. In general, this research was divided into four phases: (1) a specific field evaluation was made of ten public water supply systems that use A-C pipe and convey waters of varying quality; (2) a pilot scale A-C pipe loop was operated under controlled conditions; (3) bench scale A-C coupon tests were made; and (4) two field research projects were attempted to rehabilitate deteriorated A-C pipe in place. Each phase will be reported here separately, and followed by a general discussion.

Aggressiveness Index

AWWA Standard C400-77[1] establishes criteria for determining the quality of water that can be transported through A-C pipe without any adverse effects. These criteria are (1) nonaggressive water—use either type 1 or type 2 pipe where $pH + \log(AH) \geq 12.0$; (2) moderately aggressive water—use type 2 where $pH + \log(AH) = 10.0\text{-}11.9$; (3) highly aggressive water—$pH + \log(AH) \leq 10.0$ – serviceability of pipe must be established. It is assumed that pH = index of acidity or alkalinity of the water in standard pH units; A = the total alkalinity in mg/L as $CaCO_3$; and H = the calcium hardness in mg/L as $CaCO_3$. Type 2 pipe is autoclaved; type 1 is not.

Results

Field evaluations. Table 1 lists the ten systems that were studied, including their water quality characteristics and the calculated aggressiveness index (AI) of each. The samples for asbestos fiber counts were collected by local water utility or water supply regulatory personnel. They were collected in 946-mL (1-qt) cubetainers, preserved with mercuric chloride, and shipped to the USEPA Drinking Water Research Division (DWRD), Cincinnati, Ohio, for electron microscopic examination.[2,3] In general, precision data indicate that individual fiber counts are within a factor of three of the true value. Fiber count data are reported three ways: as a count in millions of fibers per litre (MFL); as a not statistically significant count (NSS), when a few fibers were found but not enough on which to base an accurate count; and as below detectable limit

0003-150X/80/020091-12
American Water Works Association

Reproduced from best available copy.

(BDL), when no fibers were observed. The findings pertaining to each of the ten systems will be reviewed individually.

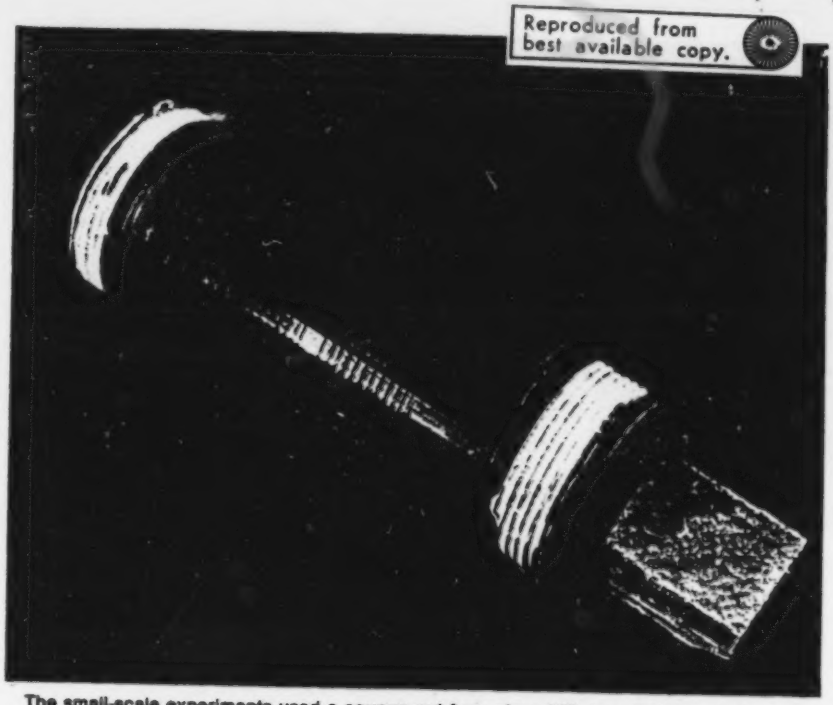
System A. System A is part of a larger utility that has a water use range of 75 000 to 94 600 m³/day (20 to 25 mgd) in winter and 113 500 to 151 400 m³/day (30 to 40 mgd) in summer. The population served by the utility is estimated at 200 000.

The water obtained from wells spread throughout the service area is very corrosive (or aggressive) and will attack all common plumbing materials except plastic. Some of the chemical qualities of the water that cause it to be so aggressive are pH 5.2, calcium hardness 1.4 mg/L as $CaCO_3$, and alkalinity 1 mg/L as $CaCO_3$, resulting in an initial aggressiveness index of 5.34 (Table 1). According to AWWA Standard C400-77[1] this quality of water makes the use of A-C pipe inappropriate, because the aggressiveness index is less than 10. However, A-C pipe was selected because it was thought to be free of the corrosion problems that were experienced with metal pipe. Lime treatment was applied at each individual well site in an effort to control corrosivity, but the lime treatment was not applied consistently, and its effectiveness has been reduced.

One section of the system is of special interest. This portion, which was originally privately owned, was begun in 1957 and added to through 1968. Much of the distribution piping was A-C pipe. Some 19 320 m (63 386 ft) were in place when the system was acquired by the municipality in 1968.

Prior to municipal ownership of system A, some A-C pipe had deteriorated considerably. Problems with the A-C pipe surfaced in 1964 when customers complained about waterborne fibers. The problem continued until a short time after stabilization treatment was instituted. Clogged customer meters and problems at a coin-operated laundry were attributed to fiber accumulation. After lime treatment was started on a continuous basis and the system was flushed and interconnected with the overall city system, customer complaints subsided. The clogging problems either were overcome or not reported. In June 1974, however, in response to a consumer complaint, visible fibers were recovered from a kitchen faucet strainer. The fibers were identified as asbestos by the USEPA in Cincinnati.

In January 1975 water samples for asbestos analysis were collected from three locations in the system—from the original well supply, from the older part of the system (sample point 1), and from the newest part of the system (sample point 2). The absence of asbestos fibers in the well samples indicated that the asbestos fibers found in the distribution system resulted from the action of corrosive water on the A-C pipe. The well water is extremely corrosive, having an aggressiveness index of 5.34. The lime-treated water in the distribution samples also qualifies as a corrosive water, at times having a pH range of 6.4 to 9.3. Although sufficient water quality data are not available to calculate the increase in aggressiveness index during distribution, it was at least 1.8 to 3.8 units higher at the two downstream sampling stations, as evidenced by the increase in pH. The increase in pH as the water flowed through the A-C pipe indicated that the pipe was altering the pH. When the pH rises as it leaches cementing material from the A-C pipe, the water becomes less aggressive to the pipe that follows.



The small-scale experiments used a coupon cut from class 150, type 2, 10-cm A-C pipe.

The most likely path water would travel to reach sample point 1 would be through 410 m (1350 ft) of 15-cm (6-in.) A-C pipe, and 200 m (655 ft) of 5-cm (2-in.) galvanized pipe. A likely path for much of the water reaching sample point 2 would be through 61 m (200 ft) of 25-cm (10-in.), 460 m (1520 ft) of 20-cm (8-in.), and 3080 m (10 100 ft) of 15-cm (6-in.) A-C pipe. The type 2 pipelines* along these routes are all between fifteen and eighteen years old, having been installed between January 1958 and September 1960.

The chrysotile fibers ranged from 0.3 to 40 μm in length and from 0.02 to 0.5 μm in diameter, although most were single fibrils of no greater than about 0.06 μm in diameter. Approximately 75 percent of the fibers were under 5.0 μm in length. The median length was 2.0 μm. Most samples contained too few amphibole fibers to be counted accurately. If all the amphiboles found in all the pipe samples are taken as a group, the amphibole fiber length ranged from 0.7 to 60 μm in length, with a median of 2.5 μm and with diameters of 0.1 to 0.2 μm.

As indicated in Table 2, asbestos fibers were found regularly in the samples taken from system A. Fiber data such as that contained in Table 2 must be interpreted cautiously, because the presence of fibers in water may be caused by drilling and tapping as well as by a release of fibers from the pipe walls or from jointing materials. In this case, however, little doubt existed that much of the fiber count in the system came from deteriorated pipe, as confirmed by inspection of excavated sections of pipe.

System B. System B had an average water use of 5960 m³/day (1.6 mgd) in 1975, serving an estimated 20 000 persons. The water is purchased from a municipal system whose surface supply has a pH of 7.2, alkalinity of 14 mg/L as $CaCO_3$, and calcium hardness of 14.5 mg/L as $CaCO_3$. The initial aggressiveness index is 9.51 (Table 1). The water is treated only by chlorination for disinfection and fluoridation for prevention of dental caries.

The path of flow to sample point 1 probably traverses 1050 m (3435 ft) of 25-cm (10-in.) and 810 m (2655 ft) of 20-cm (8-in.) A-C pipe, for a total A-C pipe length of 1860 m (6090 ft). The flow

*Johns-Manville Corp., Denver, Colo., and CertainTeed Corp. (formerly Keasby-Mattison), Valley Forge, Pa.

path to sample point 2 probably traverses 2600 m (8520 ft) of 30-cm (12-in.), 1810 m (5930 ft) of 25-cm (10-in.), 3080 m (10 100 ft) of 20-cm (8-in.), and 2000 m (6570 ft) of 15-cm (6-in.) A-C pipe for an overall distance of 9790 m (32 110 ft) of A-C pipe. All the pipe was installed from 1965 to 1967.*

Table 3 shows the asbestos fiber counts from samples taken from system B. No chrysotile fibers were found in the source water samples, although a few amphibole actinolite-tremolite fibers (presumably from native rock sources) were identified. Three samples from sample point 1 contained chrysotile fibers. All but one of the samples from sample point 2 contained chrysotile fibers. The water has a fairly short retention time from the source to sample point 1, in part because of the relatively short [1860-m (6090-ft)] distance in which the water travels through A-C pipe, but mainly because of the high flow. This line serves as a feeder line for the distribution system and to an 11 360-m³ (3-mil gal) storage tank. The water at sample point 2 has a much longer retention time. It probably flows through 9780 m (32 100 ft) of A-C pipe, and it serves only the needs of customers in this section of the system. The effect of these detention times is evident in the pH values.

The pH change from the source to sample point 1 is about 0.5 units, and to sample point 2 about 2 units. This increase in pH as well as the increase in the calcium concentration and alkalinity (Table 3) indicate that the A-C pipe serves as the source for pH adjustment and stabilization of the water in the system. As the pipe is sacrificed to provide this pH adjustment and stabilization, asbestos fibers are freed from the cement matrix through dissolution of the calcium compounds. The higher asbestos fiber counts at sample point 2 appear to be related to the added effect of the length of pipe traversed. Inspection of A-C pipe exposed to this water showed deterioration and loosened fibers.

The chrysotile fibers detected ranged from 0.2 to 10 μm in length and from 0.02 to 0.06 μm in diameter. Approximately 95 percent were under 5.0 μm. The median length was 1.0 μm. Most samples contained too few amphibole fibers to count accurately. If all thirteen of the amphiboles found in all fourteen of the pipe samples are taken as a group, the amphibole fiber length ranged from 0.7 to 15.0 μm, with a median length of 2.0 μm and a diameter of 0.1 to 0.2 μm.

System C. System C is a private system owned and operated by the users. The daily water use is about 45 m³/day (12 000 gpd), serving 41 customers (about 160 people). The water, obtained from a well source, is not treated. The well water has a pH of 7.5, calcium hardness of 82 mg/L as $CaCO_3$, and alkalinity of 88 mg/L as $CaCO_3$, resulting in an initial aggressiveness index of 11.56 (Table 1).

Sample point 1 has 170 m (550 ft) of 10-cm (4-in.) A-C pipe and 150 m (500 ft) of 6-cm (2½-in.) galvanized pipe connecting it to the well. Fourteen services are tapped off this line. The A-C pipe is type 2 and was installed in 1949.*

Sample point 2 can be supplied by two routes that form a loop. One consists of 290 m (950 ft) of 10-cm (4-in.) A-C pipe and 120 m (400 ft) of 6-cm (2½-in.) galvanized pipe. The other consists of 220 m (700 ft) of 10-cm (4-in.) A-C pipe and 305 m (1000 ft) of 6-cm (2½-in.) galvanized pipe. Twenty-seven services are tapped off this loop. The general absence of asbestos fibers (Table 4) in the samples taken from this system is attributed to the moderately aggressive water conditions indicated by the aggressiveness

*Class 150, Johns-Manville Corp., Denver, Colo.

The A-C pipe removed from system J (aggressiveness index 5.7) had been attacked and the cement binder dissolved to a depth of 0.3 cm after five years.

*Most of the pipe is Johns-Manville (Denver, Colo.) class 150 type 2, but 180 m (600 ft) of Belgian-manufactured type 2 pipe also had been laid.

TABLE 1
*Water Quality Parameters for Systems Evaluated**

System	pH	Alkalinity as $CaCO_3$, mg/L	Calcium Hardness as $CaCO_3$, mg/L	Initial Aggressiveness Index
A†	5.2	1.0	1.4	5.34
B	7.2	14	14.5	9.81
C	7.5	88	82	11.56
D	7.8	220	250	12.54
E	8.4	50	44	12.74
F	9.7	38	39	12.85
G	8.3	20	7.5	10.48
H	7.1	60	0.5	8.74
I	8.0	4.0	7.5	7.48
J	4.8	3.0	2.5	5.87

*First sampling of each study
†Before receiving lime treatment

TABLE 2
*Asbestos Fiber Counts for System A**

Date of Sample	Sample Points: Well† Amphibole	Well† Chrysotile	1‡ Amphibole	1‡ Chrysotile	2§ Amphibole	2§ Chrysotile
1/17/75	BDL	0.2	0.1	1.7	0.2	1.2
2/1/75	BDL	NSS	NSS	33	BDL	0.4
3/28/75	BDL	NSS	NSS	1.7	BDL	0.3
5/9/75	BDL	NSS	BDL	1.2	BDL	0.7
7/7/75	BDL	NSS	NSS	0.7	BDL	0.1
9/5/75	BDL	NSS	NSS	0.2	BDL	BDL
12/4/75	BDL	BDL	BDL	0.4	BDL	BDL
12/8/77	BDL	NSS	BDL	NSS	NSS	NSS
1/29/79	**	**	0.1	0.7	**	**

*Million fibers per litre
†pH 5.2, AI 5.34
‡pH 7.9, AI ≥ 7.14
§pH 9.0, AI ≥ 9.14
**Not counted

TABLE 3
*Asbestos Fiber Counts for System B**

Date of Sample	Sample Point: Control Worker† Amphibole	Control Worker† Chrysotile	1‡ Amphibole	1‡ Chrysotile	2§ Amphibole	2§ Chrysotile
2/28/75	NSS	NSS	NSS	0.2	NSS	0.4
4/29/75	BDL	NSS	NSS	NSS	NSS	0.7
5/27/75	NSS	NSS	NSS	NSS	NSS	1.6
7/29/75	NSS	NSS	NSS	0.5	NSS	0.7
8/28/75	NSS	NSS	BDL	BDL	BDL	0.9
9/30/75	BDL	NSS	BDL	NSS	BDL	NSS
11/18/75	NSS	NSS	NSS	0.2	0.1	1.3

*Million fibers per litre
†pH 7.2, Ca 5.8 mg/L as $CaCO_3$, alkalinity 14 mg/L as $CaCO_3$, AI 9.51
‡pH 7.8, Ca 8.0 mg/L as $CaCO_3$, alkalinity 18.8 mg/L as $CaCO_3$, AI 10.17
§pH 9.0, Ca 11.0 mg/L as $CaCO_3$, alkalinity 21.5 mg/L as $CaCO_3$, AI 11.78

TABLE 4
*Asbestos Fiber Counts for System C**

Date of Sample	Sample Point: Well Pump† Amphibole	Well Pump† Chrysotile	1‡ Amphibole	1‡ Chrysotile	2‡ Amphibole	2‡ Chrysotile
2/8/75	BDL	0.1	BDL	BDL	BDL	NSS
3/4/75	BDL	BDL	BDL	0.2	BDL	NSS
4/30/75	BDL	BDL	BDL	NSS	BDL	NSS
7/31/75	BDL	BDL	BDL	NSS	BDL	0.2
10/7/75	BDL	BDL	BDL	BDL	BDL	NSS
12/9/75	BDL	BDL	BDL	BDL	BDL	BDL

*Million fibers per litre
†AI 11.56
‡AI not determined

index. This pipe was not inspected.

System D. The daily water use for system D averages about 1890 m³/day (0.5 mgd), serving 2000 customers (about 7300 persons). The water is obtained from four wells about 9 m (30 ft) deep.

The raw well water hardness is 580 mg/L as $CaCO_3$, which can cause calcium carbonate deposition in water heaters and fixtures, but causes no operations difficulties for the treatment facilities or the distribution system. The raw water contains iron in excess of 1.5 mg/L, and at times enough manganese to be troublesome. The water is treated by aeration, filtration for iron and manganese removal, and chlorination for disinfection. Treatment reduces the iron to about 0.3 mg/L. The finished water quality is pH 7.8, calcium hardness of 250 mg/L as $CaCO_3$, and alkalinity of 220 mg/L as $CaCO_3$, resulting in an initial aggressiveness index of 12.54 (Table 1).

The 30-cm (12-in.) A-C main from which the samples were taken is principally a transmission line from the treatment plant to elevated storage. Only a few residential taps and no service laterals are taken from this main. The A-C pipe is type 2, and was installed in 1956.* The water passes through 1650 m (5400 ft) of 30-cm (12-in.) A-C pipe to reach sample point 1, and 2990 m (9800 ft) of 30-cm (12-in.) A-C pipe to reach sample point 2.

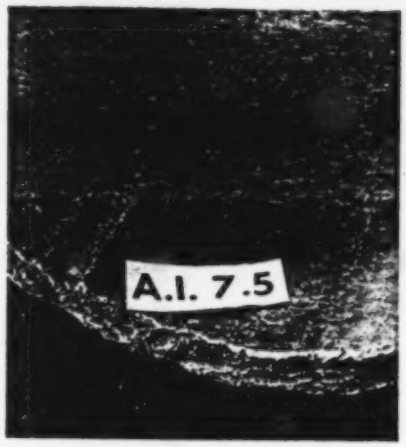
The absence of asbestos fibers (Table 5) in the samples from this system occurs because of the nonaggressive water, having deposition rather than corrosive tendencies. This pipe was not inspected.

System E. System E averages 3790 to 5680 m³/day (1 to 1.5 mgd), and serves a population of about 7200. The water is taken from four wells ranging from 92 to 111 m (302 to 365 ft) in depth. Some of the pertinent water quality parameters for these wells are given in Table 6.

As noted, well 6 has characteristics different from the other three wells. It is located 10 km (6 mi) east of the city. The other three are about 16 km (10 mi) east of the city. The better mineral quality of well 6 is offset by a hydrogen sulfide problem.

The water from the four wells is pumped to a treatment facility at the outskirts of the city. The treatment consists of aeration, lime softening, filtration, and disinfection. Tray aeration was used originally for hydrogen sulfide removal, but now serves in the iron and manganese removal process as well. Lime softening with ferric sulfate added to aid coagulation does not perform satisfactorily. Sedimentation is incomplete, and calcium carbonate is deposited in the filters and the distribution system. Treatment plant improvements are planned to correct this situation.

*Johns-Manville Corp., Denver, Colo.



A-C pipe sections from system I showed only a slight softening of the surface, despite a high aggressiveness index of 7.5.

Disinfection is accomplished by chlorination with the addition of ammonia to obtain a combined chlorine residual. The treated water, with a pH of 9.4, calcium hardness of 44 mg/L as $CaCO_3$, and alkalinity of 50 mg/L as $CaCO_3$, results in an aggressiveness index of 12.74 (Table 1), indicating a nonaggressive water.

Sample point 1 is at the end of a 5-km (3-mi) combination of 15- and 20-cm (6- and 8-in.) diameter A-C pipe. The type 2 pipe was installed in 1954-1955.* Some services are tapped off this line, but mainly it serves a park where it dead-ends. Little flow occurs in this line.

Sampling point 2 has an assortment of 20- and 30-cm (8- and 12-in.) cast iron (CI) pipe, plus a short section of 25-cm (10-in.) CI pipe for the 6 km (3¼ mi) from the

*Class 150, Johns-Manville Corp., Denver, Colo.

TABLE 5
*Asbestos Fiber Counts from System D**

	Sample Points					
	Treatment Plant†		1‡		2‡	
Date of Sample	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
6/4/75	BDL	NSS	BDL	BDL	BDL	BDL
7/8/75	BDL	BDL	BDL	BDL	BDL	BDL
8/26/75	BDL	BDL	BDL	BDL	BDL	BDL
11/24/75	BDL	BDL	BDL	BDL	BDL	BDL
4/27/76	BDL	BDL	NSS	NSS	BDL	NSS

*Million fibers per litre
†AI 12.54
‡AI not determined

TABLE 6
*Water Quality of System E**

Well Number	pH	Mn mg/L	Fe mg/L	Total Alkalinity as $CaCO_3$, mg/L	Total Hardness as $CaCO_3$, mg/L
3	7.7	0.19	1.80	191	304
4	7.5	0.15	1.24	171	216
5	7.3	0.20	1.08	168	283
6	7.9	0.05	0.02	320	48

*Finished water—pH 9.4, total alkalinity 50 mg/L as $CaCO_3$, total hardness 44 mg/L calcium as $CaCO_3$, aggressiveness index 12.74

TABLE 7
*Asbestos Fiber Counts for System E**

	Sample Point					
	Treatment Plant†		1 (A-C Pipe)‡		2 (CI Pipe)‡	
Date of Sample	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
6/17/75	BDL	BDL	BDL	NSS	BDL	NSS
9/3/75	BDL	BDL	BDL	0.1	BDL	NSS
11/11/75	BDL	BDL	BDL	BDL	BDL	BDL
2/18/76	BDL	BDL	BDL	BDL	BDL	BDL
4/27/76	BDL	NSS	BDL	NSS	BDL	BDL

*Million fibers per litre
†AI 12.74
‡AI not determined

TABLE 8
*Asbestos Fiber Counts for System F**

	Sample Point					
	Treatment Plant†		1 (A-C Pipe)‡		2 (CI Pipe)‡	
Date of Sample	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
6/26/75	BDL	0.2	NSS	0.3	BDL	NSS
9/4/75	BDL	BDL	NSS	NSS	BDL	BDL
11/18/75	BDL	BDL	BDL	BDL	BDL	BDL
2/18/76	NSS	BDL	BDL	NSS	BDL	BDL
4/26/76	BDL	BDL	BDL	NSS	BDL	BDL

*Million fibers per litre
†AI 12.85
‡AI not determined

TABLE 9
*Asbestos Fiber Counts for System G**

	Sample Point					
	Treatment Plant††		1‡		2§	
Date of Sample	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
3/2/76	BDL	BDL	NSS	0.2	**	**
10/17/77	**	**	BDL	1.1	**	**
11/2/77††	**	**	BDL	0.1	BDL	0.2
1/25/78	**	**	BDL	4.8	BDL	0.1
3/17/78	**	**	BDL	NSS	BDL	BDL
4/28/78	**	**	NSS	NSS	BDL	BDL
6/3/78	**	**	NSS	2.5	NSS	3.1
8/1/78	**	**	NSS	4.0	BDL	NSS
9/22/78	**	**	NSS	1.1	NSS	1.8
11/17/78	**	**	BDL	1.0	NSS	NSS

*Million fibers per litre
†pH 8.2-8.3, Ca 7-9 mg/L as $CaCO_3$, alkalinity 20 mg/L as $CaCO_3$, AI 10.35-10.55
‡pH 8.5-8.7, Ca 7-11 mg/L as $CaCO_3$, alkalinity 24-35 mg/L as $CaCO_3$, AI 10.73-11.28
§pH 8.7-9.2, Ca 10-17 mg/L as $CaCO_3$, alkalinity 7-11 mg/L as $CaCO_3$, AI 10.55-11.47
**Not determined
††Control measures started

treatment plant to sample point 2. The water does not pass through A-C pipe before reaching sample point 2.

The absence of asbestos fibers in the samples taken from this system (Table 7) can be attributed to the nonaggressive character of the water, as indicated by the aggressiveness index. Further, the low numbers of fibers from the CI line demonstrate that in this instance, at least, the jointing materials are not a source of asbestos fibers. This pipe was not inspected.

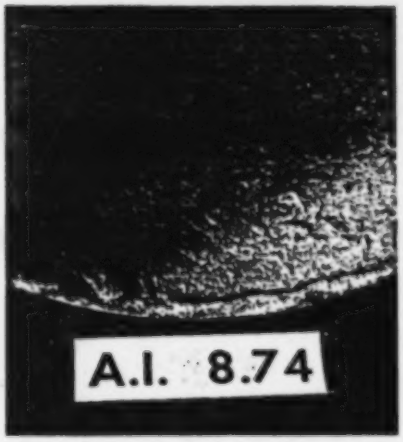
System F. System F has an average water use of 7570 m^3/day (2 mgd) and serves a population of about 20 000. The water source is a man-made reservoir. The reservoir water is pretreated by aeration for taste and odor control. The aeration also reduces the total hardness from about 130 mg/L to 96 mg/L as $CaCO_3$. The in-plant treatment consists of lime softening, ferric sulfate coagulation, polymer coagulant aid, sedimentation, filtration, and disinfection with chlorine gas. The softened water leaves the plant with a total hardness of 40 to 48 mg/L as $CaCO_3$ and a turbidity lower than 0.1 NTU. The treated water has a pH of 9.7, a calcium hardness of 39 mg/L as $CaCO_3$, and an alkalinity of 36 mg/L as $CaCO_3$, resulting in an aggressiveness index of 12.85 (Table 1), which places it in the nonaggressive water category.

One of the distribution system sampling points (1) is located after 5 km (3 mi) of 30-cm (12-in.) and 40-cm (16-in.) A-C pipe. The type 2 pipe was installed in 1973.* A few services are tapped off this line, but it serves mainly as a transmission line to an industrial user.

The other distribution system sample point (2) is located after 0.6 km (0.4 mi) of 30-cm (12-in.) CI pipe. Possibly some water at this sample point could pass through A-C pipe returning from a storage tank. The general absence of asbestos fibers (Table 8) in the samples taken from this system indicates that the water is nonaggressive, as confirmed by the aggressiveness index. As with system E, few fibers were present in water flowing through the CI pipe. The A-C pipe was not inspected.

System G. System G is a municipal water system using a surface water supply. The water is given conventional treatment followed by pH adjustment to 8.2 by the addition of NaOH. The daily water use is about 28 400 m^3/day (7.5 mgd). The population served is 40 000. Table 1 places this water in the moderately aggressive category; its aggressiveness index value is 10.48.

Table 9 contains the asbestos fiber counts and water quality ranges found in system G. Sample point 1 follows 4.1 km (13 000 ft) of A-C pipe, while sample point 2 follows 1.8 km (6000 ft) of A-C pipe. Both segments are of type 2 pipe.



Inspection of pipe sections from system H (aggressiveness index 8.74) revealed cement binder dissolution to 0.3 cm.

In Table 9 the increase in pH from the treatment plant to sample point 1 is greater than to sample point 2. The calcium concentrations also increase more over the longer run of A-C pipe to sample point 1. The calcium hydroxide or other calcium products in the cement binder are being dissolved, causing an increase in pH and calcium in the water. This again demonstrates that a water that is aggressive toward A-C pipe will continue to increase in pH and calcium with time of exposure, as the water seeks its calcium saturation level. Despite the loss of calcium by the A-C pipe, inspection showed that the pipe had not been softened, although some pitting of the pipe was observed.

The asbestos fiber data in Table 9 must be analyzed carefully to avoid misleading interpretations. The water leaving the treatment plant contained no asbestos fibers. This means that asbestos fibers found in the distribution system came from the pipe materials. However, the large fluctuation in the number of fibers found in various samples from both points in the distribution system—from below detection limits to over 4 MFL—does not necessarily indicate severe deterioration of the pipe. The higher fiber counts occurred after tapping of the A-C pipe in the sample collection area. Therefore, asbestos fiber counts from individual samples do not always provide a true indication of A-C pipe condition.

The DWRD has a research grant with this utility to study methods of reducing fiber release from the A-C pipe by adding zinc orthophosphate to the water. This study is underway.

System H. System H is a privately owned water system with a well water source. The daily water use for system H is 380 m^3/day (0.1 mgd), serving a population of 1200. This water has a high iron content, so a zeolite water softener was installed to remove the iron. The softener also removed the calcium from the water and created a very aggressive finished water (Table 1). Table 10 gives the water quality data and the asbestos fiber counts for system H.

Water from sample point 1 had passed through about 1530 m (5000 ft) of A-C pipe; water from sample point 2 passed through about 1830 m (6000 ft) of a combination of A-C and PVC pipe; and water from sample point 3 passed through about 3350 m (11 000 ft) of A-C pipe, all type 2.

Despite the apparently small change in pH and calcium in samples taken from the treatment plant and sample point 1 (a distance of 1500 m), the asbestos fiber counts in the water were quite high. Water quality data from sample points 2 and 3, if measured, might have shown increases more typical of an aggressive system. The aggressiveness index of 8.74 classifies this water as very aggressive. The high fiber counts observed at all sample points indicate that the A-C pipe is being attacked. Inspection of the pipe revealed that the cement binder had been dissolved to a depth of about 0.3 cm (⅛ in.).

The DWRD has a research contract with this utility to attempt to rehabilitate the pipe, after it is cleaned using the McCauley processes.[4,5]

System I. System I is a municipal water supply with two surface and three well sources for its water. All of the waters are soft with low alkalinity. The water quality characteristics for the source waters are pH from 6.4–6.6, alkalinity from 4 to 23 mg/L as $CaCO_3$, and calcium concentrations from 2 to 14 mg/L as $CaCO_3$. The only treatment provided is chlorination, which at times lowers the pH below 5. The water use stands at about 11 300 m^3/day (3 mgd), serving a population of about 25 000. The distribution system contains about 87 km (54 mi) of type 2 A-C pipe and 81 km (50 mi) of CI pipe. Sample point 1 is located after 4040 m (13 250 ft) of A-C pipe; sample point 2 is located after 1770 m (5800 ft) of A-C pipe. Sample point 3 is at a dead end after 2820 m (9350 ft) of A-C pipe.

The data from System I proved to be quite puzzling but informative. The water entering the distribution system had an aggressiveness index ranging from 6.0 to 7.5, a severely aggressive water. Very high asbestos fiber counts were expected in all the water samples. Table 11 shows that this was not true at sample points 1 and 2. Further, the pH had not increased significantly at sample points 1 and 2. At sample point 3 a large pH increase and very high asbestos fiber counts were observed, indicative of A-C pipe deterioration.

A-C pipe sections were removed from the system to locate the deteriorated

*Class 150, Johns-Manville Corp., Denver Colo.

areas. None of the pipe showed any signs of deterioration, other than a slight softening of the surface. No visible asbestos fibers were found. The pipe section from the dead-end sample (sample point 3) had markings along the sides, indicating that 5–8 cm (2–3 in.) of debris had collected in the bottom. Because the pipe had not deteriorated, the high asbestos fiber counts must have come from the stirred-up debris that had probably collected from pipe tappings.

All of the excavated A-C pipe was coated with what appeared to be iron rust, which may have protected the pipe from deterioration. The iron content in the water ranged between 0.1 and 0.15 mg/L. Whether or not the iron alone was responsible for the protection of the pipe is not known. Protection of A-C pipe by an iron rust-like coating has been observed in laboratory experiments and reported to the authors from existing systems. Efforts are being made to identify the reactions in this protective phenomenon, but the results are not available at this time.*

Relating the very high asbestos fiber counts at sample point 3 to drilling and tapping of the A-C pipe, and not general pipe deterioration, suggests the need for increased caution in evaluating the condition of A-C pipe only by the examination of a single water sample for asbestos fiber content.

System J. System J is a municipal well water supply of 2270 m³/day (0.6 mgd) that serves a population of 3500. System J sample points 1, 2, and 3 are located after 925 m (3035 ft), 2070 m (6780 ft), and 1825 m (5980 ft) of type 2 A-C pipe, respectively. Table 12 gives the asbestos fiber count data. The A-C pipe that was removed from system J had been attacked, and the cement binding compound had been dissolved to a depth of about 0.3 cm (⅛ in.) after five years. This result is to be expected from a calcium-starved water, which would attack almost all piping materials in general use for drinking water transmission and distribution.

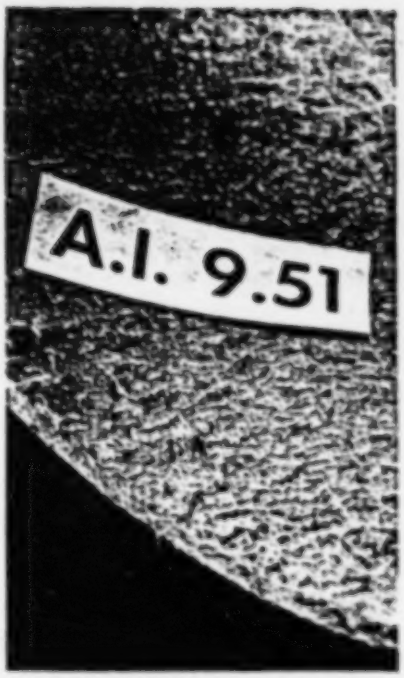
In-House Research

A-C pipe experimental pipe loop. In late 1973 the USEPA DWRD investigated the performance of A-C pipe exposed to a variety of water quality conditions. At the time advisors knowledgeable about the performance of A-C pipe suggested that small laboratory bench scale experiments would not be acceptable for A-C pipe studies. DWRD proceeded, therefore, to put a recirculating pilot scale experimental pipe loop into operation, using several full lengths of 10-cm (4-in.) and 15-cm (6-in.) diameter type 2 A-C pipe. This experiment was started in late 1974 and operated until mid-1977.

Although these experiments were not considered successful, the pipe loop produced a few worthwhile findings. The most important of these were that

1. The iron dissolved in the water would precipitate to provide a protective coating to the A-C pipe, even under highly aggressive water quality conditions. For example, a water with a pH of 5.5, a calcium concentration of 10 to 15 mg/L as $CaCO_3$, and a total alkalinity of 1 to 3 mg/L as $CaCO_3$, initially showed signs of being aggressive to the A-C pipe by leaching calcium from the pipe early in the experimental run. Later, iron dissolved from some of the experimental equipment combined chemically in some way with the pipe wall to provide a protective coating on the A-C pipe. This halted the leaching of the calcium and release of asbestos fiber.

2. Under the pipe loop experimental conditions, waters indexed as moderately aggressive attacked type 2 A-C pipe. This result was not predicted. The attack on the A-C pipe during these moderately aggressive experimental conditions was exaggerated, when compared to actual water system conditions. In tests with aggressiveness indices of 10.4 and 11.7 the A-C pipe was softened. The aggres-



The initial aggressiveness index of system B was 9.51; both sample points 1 and 2 contained chrysotile fibers.

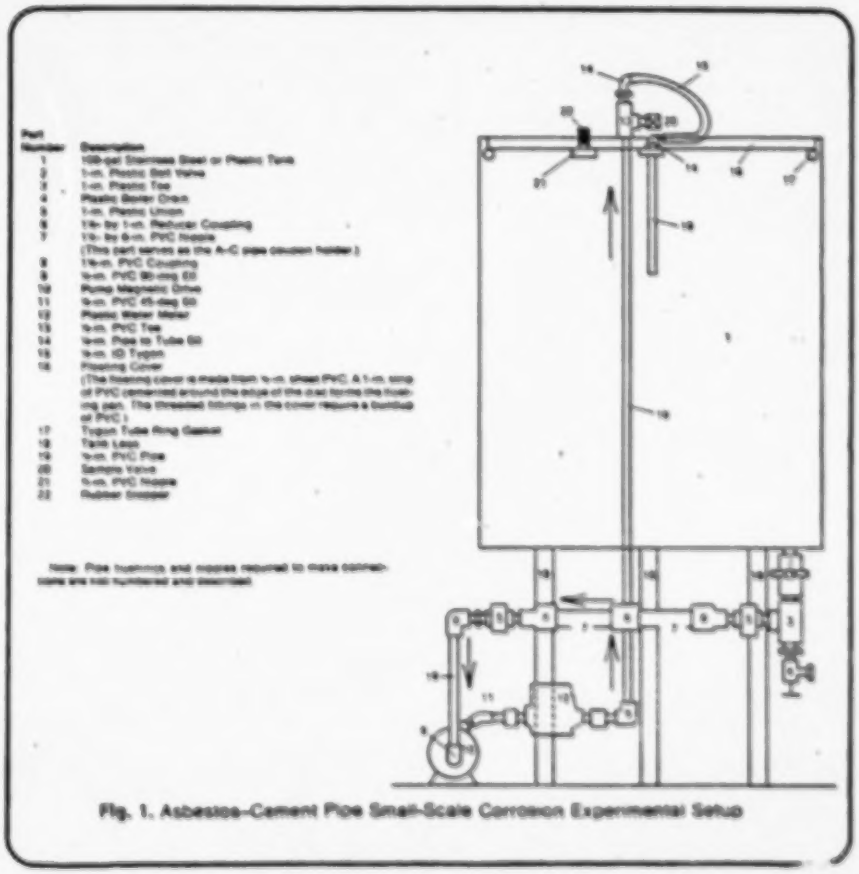
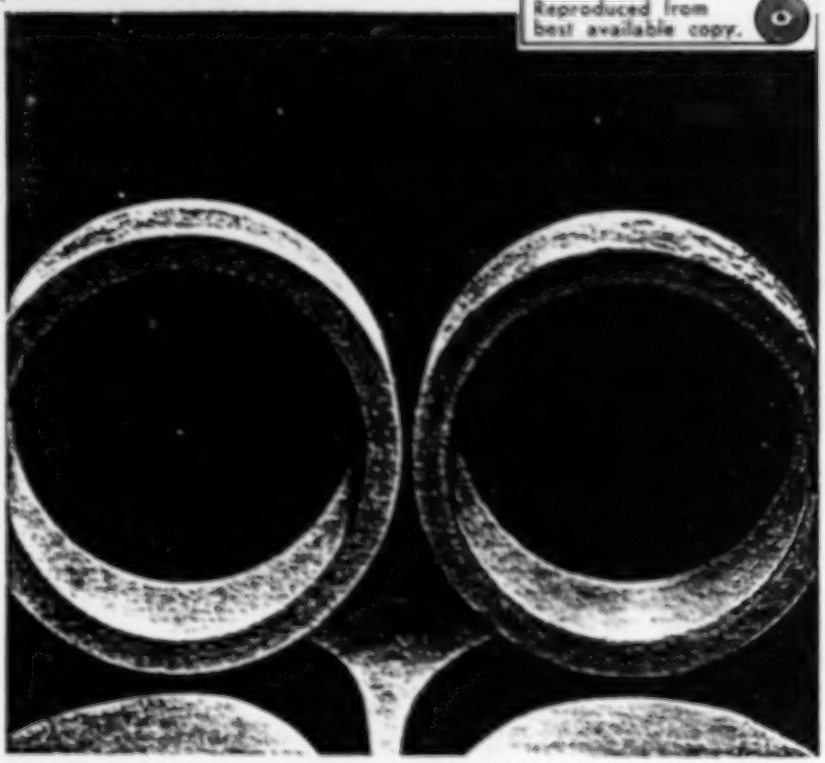

Part Number
Description
1 10lb-gal Stainless Steel or Plastic Tank
2 1-in. Plastic Ball Valve
3 1-in. Plastic Tee
4 Plastic Barbed Check
5 1-in. Plastic Union
6 1¼- by 1-in. Reducer Coupling
7 1½- by 6-in. PVC Nipple
(This part serves as the A-C pipe coupon holder.)
8 1½-in. PVC Coupling
9 6-in. PVC 90-deg Ell
10 Pump Magnetic Drive
11 6-in. PVC 45-deg Ell
12 Plastic Water Meter
13 6-in. PVC Tee
14 6-in. Pipe to Tube Ell
15 6-in. ID Tygon
16 Flapping Cover
(The flapping cover is made from ¼-in. sheet PVC. A 1-in. strip of PVC cemented around the edge of the cover forms the hooking part. The threaded fittings in the cover require a bushing of PVC.)
17 Tygon Tube Ring Gasket
18 Tank Lead
19 ¼-in. PVC Pipe
20 Sample Valve
21 ¼-in. PVC Nipple
22 Rubber Stopper
Note: Pipe fittings and nipples required to make connections are not numbered and described.

Fig. 1. Asbestos-Cement Pipe Small-Scale Corrosion Experimental Setup

*Research grant R-803638, Zoltek, Univ. of Massachusetts.

Reproduced from best available copy.



The water quality data for a piece of pipe 30 years old (right) from a system with an 11.2 aggressiveness index give no hint as to what helped create and maintain this excellent pipe surface, as compared to the new pipe on the left.

siveness index 10.4 test resulted in a more severe attack than the 11.7 test.

During both of these experiments the water was not saturated for calcium carbonate; it was maintained in an unstable condition through pH, alkalinity, and calcium adjustments. The aggressiveness index 11.7 conditions were achieved by maintaining a pH of 7.5, a calcium concentration of 150 mg/L as $CaCO_3$, and an alkalinity of 100 mg/L as $CaCO_3$. Continuous feed of sodium bicarbonate to maintain the desired alkalinity was opposed by continuous feed of HCl to maintain the pH at 7.5. The difficulties encountered in maintaining the pH and the alkalinity at the desired concentrations were caused by the operation of a system in which the water was in contact with carbon dioxide in the atmosphere in an open reservoir.

Softening of A-C pipe has been observed in A-C pipe installations with moderately low aggressiveness indices, but not as severely as occurred under the pipe loop conditions. This demonstrated the importance of stable water conditions when evaluating A-C pipe performance, and the importance of sealed laboratory A-C pipe or other corrosion experiments. The unsealed pipe loop did not represent field conditions.

3. Pipe drilling and tapping operations can greatly influence asbestos fiber counts in water. During the A-C pipe loop experiments the pipe was drilled and tapped under pressure with water flowing through the pipe. The first tapping experiment was performed using a standard pipe-tapping machine with no chip-flushing arrangement. Tapping caused the asbestos fiber counts to increase considerably. Two weeks elapsed before the fiber counts returned to the level before tapping, in spite of filtration for removal of all of the fibers with each pass of recirculating water.

In a later experiment A-C pipe was tapped under the same conditions, except that the tapping machine had been modified by the installation of a blowoff valve to flush out A-C pipe chips and debris created during the drilling and tapping operations. In this case, the asbestos fiber counts increased during tapping, but returned to before-tapping levels by the next day.

The flushing valve was wide open throughout the drilling and tapping operation. Much debris was collected from the flushing stream. The flushing valve must be fully open during drilling and tapping because without a strong continuous flow much of the debris will fall into the pipe.

Many regular pressure tapping machines can be modified by adding a flushing valve using a commercially available kit. New tapping machines can be purchased with a flushing valve.

A-C Coupon Tests

General description. The unsatisfactory performance of the pilot scale A-C pipe experiments led to the conclusion that bench scale, better-controlled testing should be tried despite the belief that small-scale results might be misleading. Figure 1 shows the bench scale experimental setup with the important components identified. Anyone desiring more detailed information regarding this equipment should contact the authors.

The A-C pipe used in this type of experiment is a coupon cut from class 150, type 2, 10-cm (4-in.) pipe. The coupon is 15 cm (6 in.) long and wide enough to fit closely inside a 4-cm (1½-in.) PVC pipe (part 7 on Fig. 1). The cut edges of the coupon are sealed.

This experimental arrangement was designed to allow ease in operation and extended use of recirculated water between changes. The 380-L (100-gal) volume of the recirculating water reacting on a small piece of A-C pipe satisfied this objective. The water is recirculated continuously through the PVC pipe that holds the A-C coupon. The water flows at a rate of 0.2 L/s (3 gpm), providing a velocity of about 0.35 m/s (1 fps) past the coupon, a reasonable flow.

General water quality control. Few water quality characteristics were controlled or monitored, these being the concentrations of calcium, alkalinity, free residual chlorine, and pH. The temperature and total dissolved solids (TDS) concentrations also were measured, but were not controlled. Concentration of dissolved oxygen (DO) and carbon dioxide (CO_2) were measured during the early experiments. The CO_2 concentrations were found to be insignificant, while the DO concentration always was relatively high (6–8 mg/L), so these were measured only occasionally. The desired calcium concentration was achieved by diluting Cincinnati tap water with deionized water. The alkalinity was adjusted by the addition of sodium bicarbonate. The pH was regulated by the addition of sodium hydroxide or hydrochloric acid. The free chlorine residual concentration was maintained at a minimum of 0.2 mg/L by use of a chlorine solution made from chlorine gas. (Calcium hypochlorite would have added calcium.)

Development of testing protocol. Because of the pilot pipe loop experiments the problems caused by exposure of the water to atmospheric CO_2 were known, but with a continuous automatic water quality adjustment arrangement (as was used with the pipe loop experiments) the severity of the CO_2 effects were not fully realized. The first bench scale experiments used a loosely covered reservoir to keep out dust and to reduce evaporation.

During these first experiments, pH values of 7.0 and 8.2 were established to investigate possible trends. Low calcium and alkalinity concentrations, 3–10 mg/L calcium as $CaCO_3$ and a total alkalinity of 20 mg/L as $CaCO_3$, were used. These experiments were intended mainly for the development of testing procedures. After acceptable operational procedures were developed, these early experiments were repeated under better-controlled conditions.

Experiments conducted using the water in the loosely covered reservoir, performed at pH 8.2, experienced a gradual alkalinity increase. The pH had to be adjusted daily because it would drop almost 0.2 units each day. When the pH was set at 7.0, a daily increase of 0.2 to 0.3 pH units was observed, as well as a continuous decline in alkalinity, both of which required daily correction and attention. Despite the water quality control problems experienced in this set of experiments the behavior of A-C pipe was indicated. The water in the pH 7.0 tests was more aggressive toward the A-C pipe coupon than the water in the pH 8.2 tests, as indicated by surface softening.

The difficulty in controlling water quality using loosely covered reservoirs led to some small laboratory top-sealed experiments which demonstrated that pH drift could be eliminated by sealing the water from the atmosphere. Floating covers were installed on the recirculation tanks to produce sealed systems. Not only did this measure help maintain water quality, but the sealed system was considered more representative of a water distribution network than one with exposure to the atmosphere.

When a sealed system is used, precautions must be taken in making pH determinations. The pH of water taken from a sealed system can easily vary 0.2 to 0.8 pH units from the actual pH, if the pH is measured using a pH meter with the sample exposed to the atmosphere. This type of pH variation or drift occurs with many well waters as well as many distribution system samples, but usually goes unnoticed and accounts for many inaccurate pH readings. A method for determining accurate pH values using sealed conditions that eliminates pH drift has been developed and can be obtained from the authors of this paper.

Use of the sealed systems reduced the need for pH adjustment in a pH 8.2 system to once a week, and this adjustment was needed mainly to counteract the effect of weekly chlorination. The pH 7.0 sealed systems rarely required any pH adjustment, in contrast to the daily adjustment needed in the loosely covered systems. The alkalinity in both the pH 7.0 and 8.2 systems never required adjustment through an entire experimental run of six to eight months. Although the water quality does change during a test because of recirculation, the changes are slight. Tests where the water was changed in mid-run showed that the rate of calcium dissolution was the same after the change of water as it was just before the change. Therefore, the results seem applicable to a "once-through" system. A standardized testing protocol for a once-through system was established.

Description of experiments and results. Table 13 lists the water quality conditions for bench scale experiments. In some experiments zinc compounds were tested as a possible protection for A-C pipe. The observation of iron and manganese compounds coating and protecting A-C pipe both in the field and in the pilot scale pipe loop raised the possibility that zinc might act in the same manner. Both iron and manganese have demonstrated protection potential, but they are undesirable as an additive to finished drinking water. Zinc is not undesirable in low concentrations in drinking water and is used in corrosion control compounds for metal pipes. The effect of zinc on industrial processes has yet to be determined. The use of very low calcium and alkalinity concentrations in experi-

TABLE 10
*Asbestos Fiber Counts for System II**

	Sample Points							
	Treatment Plant†		II		III		IV	
Date of Sample	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
9/15/78	BDL	BDL	0.7	10	**	**	**	**
10/15/78	**	**	**	**	BDL	4.3	NSS	0.7

*Million fibers per liter
†pH 7.1, Ca 0.5 mg/L as $CaCO_3$, alkalinity 80 mg/L as $CaCO_3$, Al 0.74
‡pH 7.2, Ca 2.0 mg/L as $CaCO_3$, alkalinity 92 mg/L as $CaCO_3$, Al 0.48
§Al not determined
**Not determined

TABLE 11
*Asbestos Fiber Counts for System I**

	Sample Points							
	Combination of Sources After Cl,†		II		III		IV** (Dead End)	
Date of Sample	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
6/25/75	BDL	NSS	BDL	0.1	††	††	††	††
9/12/75	††	††	BDL	0.2	††	††	††	††
6/30/76	††	††	BDL	0.1	††	††	††	††
7/28/76	††	††	††	††	NSS	NSS	9.6	180

*Million fibers per liter
†pH 6.5–6.8, Ca 5.0–7.5 mg/L as $CaCO_3$, alkalinity 4.0 mg/L as $CaCO_3$, Al 0.0–7.3
‡pH 6.7–6.8, Ca 6.0–8.0 mg/L as $CaCO_3$, alkalinity 1–4 mg/L as $CaCO_3$, Al 5.28–7.08
§pH 9.0, Ca 7.5 mg/L as $CaCO_3$, alkalinity 4.0 mg/L as $CaCO_3$, Al 7.46
**pH 9.0, Ca 33.5 mg/L as $CaCO_3$, alkalinity 16 mg/L as $CaCO_3$, Al 11.61
††Not determined

TABLE 12
*Asbestos Fiber Counts for System J**

	Sample Points							
	Well Source†		II		III		IV	
Date of Sample	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile	Amphibole	Chrysotile
6/30/78	NSS	0.8	BDL	100	NSS	300	1	1
10/25/78	1	1	1	1	1	1	NSS	1.00

*Million fibers per liter
†Al 5.07
‡Al not determined
§Not determined

ments 1 through 5 was intended to imitate the water quality at an EPA research grant site in system G.

Experiment 1 (pH 8.2, Ca 6 mg/L as $CaCO_3$, alkalinity 20 mg/L as $CaCO_3$, AI 10.28). During six months of operation the alkalinity in the water increased from 20 to 26 mg/L as $CaCO_3$. The calcium concentration also had increased from 5.3 to 13.5 mg/L as $CaCO_3$ during this period, indicating that some dissolution of the A-C pipe had occurred. Examination of the coupon confirmed this assumption, because the inner pipe surface was softened and could be gouged with a fingernail. (Although the flowing water contacts both the inside and outside of the A-C coupon, and this might influence the absolute magnitude of the changes in the concentrations of calcium and alkalinity, the result of the experiment is judged from the examination of the condition of only the inner wall of the coupon.)

Experiment 2 (pH 8.2, Ca 6 mg/L as $CaCO_3$, alkalinity 20 mg/L as $CaCO_3$, AI 10.28, zinc orthophosphate). Experiment 2 differs from experiment 1 only in the addition of zinc orthophosphate to produce a zinc concentration of 0.3 to 0.5 mg/L. The alkalinity in the recirculated water increased from 20 to 25 mg/L as $CaCO_3$, and the calcium concentration from 5.0 to 6.1 mg/L as $CaCO_3$, in six months. Mah and Bostman[7] also reported no apparent loss of calcium by A-C pipe during experiments using zinc orthophosphate. The small calcium increase in the water suggested little or no attack on the A-C pipe. Examination showed that the coupon had retained its hard and smooth inner surface condition. A light gray coating on the pipe surface could be scratched through to the darker gray color of unused A-C pipe. The A-C pipe appeared to be well protected by the zinc in the water.

Experiment 3 (pH 7.0, Ca 10 mg/L as $CaCO_3$, alkalinity 20 mg/L as $CaCO_3$, AI 9.3). During six months of operation with lower pH water, the alkalinity in the recirculation water increased from 20 to 23 mg/L as $CaCO_3$, and the calcium concentration increased from 10 to 20 mg/L as $CaCO_3$. The calcium increase predicted the dissolution of the cement from the coupon, which was confirmed by the softening of the pipe observed during the final examination.

Experiment 4 (pH 7.0, Ca 10 mg/L as $CaCO_3$, alkalinity 20 mg/L as $CaCO_3$, AI 9.3, zinc orthophosphate). Experiment 4 differs from experiment 3 only in the use of zinc orthophosphate. During six months the alkalinity in the water increased from 20 to 29 mg/L as $CaCO_3$, and the calcium concentration from 10 to 17 mg/L as $CaCO_3$. The calcium increase was almost as great as that of experiment 3 where no zinc orthophosphate was used. Inspection revealed that the A-C pipe coupon was softened somewhat, as expected from the calcium data. The pipe coupon condition was better than in the pH 7.0 and pH 8.2 experiments when no zinc was present.

Experiments 1 through 4 clearly established that the pH must be higher for the zinc to protect the pipe. The order of performance from best to worst was pH 8.2 plus zinc, pH 7.0 plus zinc, pH 8.2, and pH 7.0.

Experiment 5 (pH 8.2, Ca 6 mg/L as $CaCO_3$, alkalinity 20 mg/L as $CaCO_3$, AI 10.28, zinc chloride). During the zinc orthophosphate experiment the zinc was depleted gradually, but the phosphate was not. This indicated that the protection provided might be related to the zinc alone and not to the form of the zinc compound used. Zinc chloride was suggested as a source for the zinc.[8]

Experiment 5 repeated experiment 2, with zinc chloride substituted for zinc orthophosphate. The operation and results of the two experiments were practically identical. A slight increase in the calcium concentration occurred during the first three weeks of the six-month test, but none thereafter. The zinc concentration declined quite rapidly early in the study, when it was reduced from a concentration of 0.7 mg/L to 0.4 mg/L in three weeks. During the latter part of this experiment, the zinc decreased by this same amount in 21 weeks. It is possible that some early conditioning of the system affected the results.

This experiment demonstrated that zinc in various compounds could be used to protect A-C pipe. The A-C coupon at the end of this test was clean and hard with a light gray colored film on the surface.

Experiments 6 and 7 (pH 7.5 (6) and 7.9 (7). Ca 145 mg/L as $CaCO_3$, alkalinity 125 as $CaCO_3$, AI 11.76 (6) and 12.16 (7)). Experiments 6 and 7 were companion tests to demonstrate the performance of $CaCO_3$ as a protective agent under both saturated and unsaturated conditions, with pH being the variable to control the $CaCO_3$ saturation. According to Caldwell-Lawrence diagrams,[9] a water similar to that used in these experiments would be saturated for $CaCO_3$ at a pH of about 7.75 (pH_s) with a calcium concentration of 145 mg/L as $CaCO_3$, and alkalinity of 125 mg/L as $CaCO_3$, a temperature of 23.5°C, and TDS of 350 mg/L. Experiment 6 at pH 7.5 was operated with a slightly negative Langelier index; experiment 7 at pH 7.9 had a slightly positive Langelier index.

At the end of 31 weeks the A-C coupon in the pH 7.5 water was softened and appeared to have acquired a light coating. On the other hand, the A-C coupon in the pH 7.9 system remained hard and clean. The slight change in pH from below pH_s at pH 7.5 to above pH_s at pH 7.9 is equivalent to about 40 mg/L calcium as $CaCO_3$, if calcium rather than pH was the parameter used to alter conditions. Experiment 6 demonstrates that a water unstabilized with respect to $CaCO_3$ will attack A-C pipe despite a high aggressiveness index of 11.76. This exaggerated situation probably would not occur naturally, but it does point out that placing absolute confidence in a single water quality parameter for all waters is not reasonable.

Experiment 8 (pH 9.0, Ca 25 mg/L as $CaCO_3$, alkalinity 40 mg/L as $CaCO_3$, AI 12.00, at pH_s).

Experiment 8 tested a water at $CaCO_3$ saturation.[9] Inspection of the inner wall of the coupon from this test showed that it was very slightly softened after 31 weeks. The results of experiment 8 fell between those of experiments 6 and 7 with respect to the hardness of the inner wall of the A-C pipe coupon.

These tests will continue, testing other water quality parameters and corrosion protection techniques. A mechanical device will be used to compare the final condition of the inner pipe wall.

TABLE 13
Water Quality Conditions for Bench Scale Experiments

Experiment Number	pH	Calcium as $CaCO_3$, mg/L	Total Alkalinity as $CaCO_3$, mg/L	Aggressiveness Index	Corrosion Control Method
1	8.2	6	20	10.28	none
2	8.2	6	20	10.28	zinc orthophosphate
3	7.0	10	20	9.30	none
4	7.0	10	20	9.30	zinc orthophosphate
5	8.2	6	20	10.28	zinc chloride
6	7.5	145	125	11.76	none
7	7.9	145	125	12.16	slightly positive Langelier index*
8	9.0	25	40	12.00	$CaCO_3$ saturation

*"Langelier index" = $pH - pH_s$, = pH at calcium carbonate saturation

Discussion

Field evaluation studies. A field evaluation was made of ten water utilities using A-C pipe and having various water qualities. Samples of the water were taken before and after it entered the pipe and then examined under an electron microscope to determine the possible release of asbestos fibers from the pipe walls. The combinations of pH, alkalinity, and

[7] G.T. Daigger, assoc. prof. chem., Univ. of Massachusetts.

calcium-hardness in these ten utilities' waters produced aggressiveness indices, as defined by AWWA Standard C400-77,[1] from 5.34 to 12.85. Five were below 10.0, two were between 10.0 and 12.0, and three were above 12.0 as the water entered the distribution system. Of the three above an aggressiveness index of 12.0, one had a moderate pH (7.8) but high alkalinity and calcium hardness, while the other two had higher pHs, 9.4 and 9.7, but lower values for the other two factors in the index. A reasonable spread of water quality factors was covered (Table 1).

Asbestos fiber counts and pipe conditions. Consistently quantifiable asbestos fiber counts were found in four of the five systems with an aggressiveness index below 10.0, and in one of the systems with an aggressiveness index above 10.0 (Table 14). The three systems with an aggressiveness index over 12 and the one with an aggressiveness index of 11.36 showed no asbestos fibers, or fibers very inconsistently, regardless of the combinations of pH, alkalinity, and calcium hardness. Inspection of the pipe from system I with an aggressiveness index below 10 (7.46) that did not have consistent asbestos fiber counts revealed a protective iron rust-like coating on the A-C pipe.

Although pipe from systems with a higher aggressiveness index was not inspected, inspection of a piece of pipe 30 years old from a system with a pH of 7.2, a calcium concentration of 124 mg/L as $CaCO_3$, alkalinity of 75 mg/L as $CaCO_3$, and an aggressiveness index of 11.2, revealed the pipe wall to be sound and hard. The pH at calcium carbonate saturation for a water with these calcium and alkalinity concentrations is higher than 8.0, yet this water has provided a very smooth lining inside the pipe at pH 7.2. The water quality data give little hint as to what helps create and maintain this excellent interior pipe surface. Elements that are known to coat and protect the pipe could not be visually detected through the color of the coating. The rust color from iron, the black color from manganese, or the gray color from zinc did not stand out. The concentrations of these elements in the water were 0.05 mg/L iron, 0.004 mg/L manganese, and 0.01 mg/L zinc. These concentrations are quite low, but protection by iron compounds at slightly over 0.1 mg/L iron was reported in system I. Further investigation of the effect, if any, of low levels of these apparently protective materials is needed.

Patterns of pipe attack. When an aggressive water passes through A-C pipe, the pH and calcium content increase causing the aggressiveness index to increase because the water dissolves the cement out of the pipe. This phenomenon is well demonstrated by the increase of these factors in the water in system B between the source and sample points 1 and 2. This change then caused the aggressiveness index to rise from 9.51 at the source, to 10.17 at sample point 1, to 11.78 at sample point 2 (Table 3). The much greater length of A-C pipe between sample point 1 and sample point 2 than between the source and sample point 1 caused the greater increase in aggressiveness index (1.61 units versus 0.66 units), even though the rate of the aggressiveness index increase will slow as a stabilized water condition is approached in a given segment of a distribution system.

System A demonstrates this same condition between the source and its sample point 1 and sample point 2 (Table 2). The dissolution of the cement causes deterioration of the pipe and the release of asbestos fibers. The longer the water is exposed to the A-C pipe, the greater are the increases in pH and calcium, which cause the water to become less aggressive. Therefore, major pipe deterioration usually will occur in the sections of pipe that are located just after the water enters the A-C pipe distribution system.

The travel time or time of exposure needed to stabilize the water at the expense of the A-C pipe can occur either through long or short lengths of pipe, depending on the water velocity. A section of pipe farther from the source will not always be attacked less than pipe

TABLE 14
Summary of Data Collected

System	Initial Aggressiveness Index	pH	Alkalinity as $CaCO_3$, mg/L	Calcium Hardness as $CaCO_3$, mg/L	Consistently Quantifiable Fibers	Pipe Wall Determined as Determined by Inspection
A	9.51	8.0	1.0	1.0	yes	yes
I	9.97	6.8	5.0	2.0	yes	yes
I	7.46	6.6	6.0	7.0	no	no
D	9.79	7.1	46	6.0	no	no
E	9.51	7.2	10	10.0	yes	yes
G	10.49	6.1	10	7.0	yes	yes
C	11.36	7.0	40	40	no	*
C	11.56	7.0	40	40	no	*
D	12.04	7.0	200	200	no	*
B	10.79	8.6	70	46	no	*

*Not inspected

TABLE 15
Summary of A-C Pipe Coupon Tests

Experiment Number	pH	Aggressiveness Index	Additive	Inner Wall of Coupon Tuberous
3	7.0	9.0	none	yes
4	7.0	9.0	zinc orthophosphate	slightly
1	9.2	10.35	none	yes
2	9.2	10.48	zinc orthophosphate	no
5	9.6	10.48	zinc chloride	no
6	7.5	11.78	none (slightly more pH)	slightly
8	9.0	12.00	none (at pH 9)	very slightly
7	7.0	12.58	none (slightly over pH 9)	no

TABLE 16
*Chrysotile Asbestos Fiber Counts for Systems A and I**

Sample Point	System A†	System I‡
Source	825, 4.6	1.0
1	1000–10	100
2	825–1.6	100

*Million fibers per liter.
†Initial: 10; 1.75.
‡Initial: 10; 5.67.

closer to the source, because of different flow patterns through different distribution lines. Specimens of pipe cut from one part of system A showed that pipe farther from the plant was protected by stabilization of the water through the dissolution of cement from A-C pipe closer to the source. Specimens from other parts of system A demonstrated that pipe near the source and at a considerable distance from the source could be attacked with equal severity.

When water passes quickly through the first portion of the distribution line, it does not have time to dissolve enough cement to reduce its aggressive nature significantly before it flows farther out in the line. Water under these conditions is almost as aggressive in the distribution system as it is near the source. The pipe in the system where flow rates have slowed will be attacked almost to the same degree as pipe in other parts of the system that are near the source because they are both exposed to an aggressive water for the same length of time.

Pipe loop studies. Two 27-m (90-ft) lengths of A-C pipe, one 10 cm (4 in.) and one 15 cm (6 in.) in diameter, were tested in a recirculating system with some fiber removed during each pass. Because the recirculation reservoir was open to the atmosphere, this test procedure was not representative of the performance of pipe in actual distribution systems. Studies of tapping in this system showed how easily fiber counts could be influenced by pipe tapping. Contact between water and the atmosphere had to be prevented; the influence of atmospheric carbon dioxide on the chemical quality of the water would skew the performance of A-C pipe in small-scale tests.

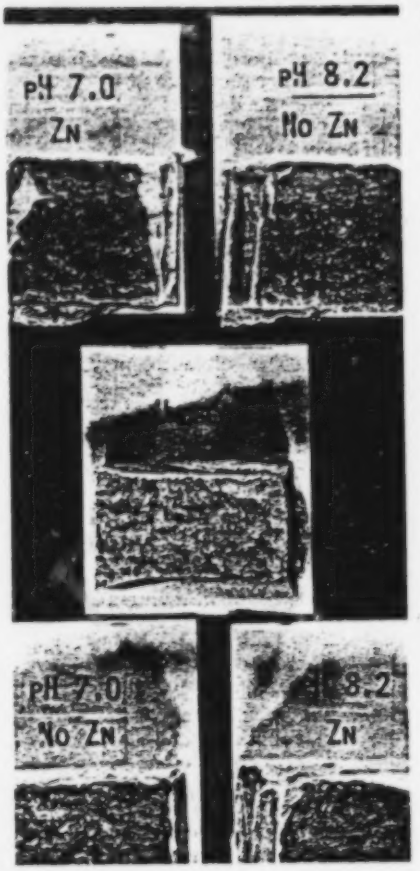
A-C coupon tests. An apparatus closed to the atmosphere was designed to recirculate water past an A-C pipe coupon (Fig. 1). This device was used to evaluate the influence of water chemistry and various corrosion control additives on the condition (hardness) of the inner surface of A-C pipe. Table 15 summarizes the data obtained. These data suggest that

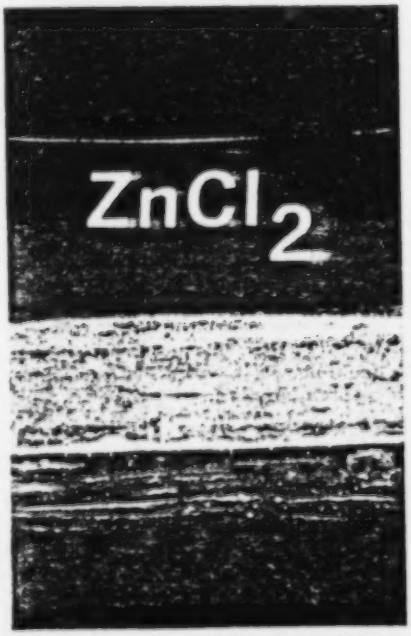
1. Small-scale experiments can be used to evaluate the performance of A-C pipe under various water quality conditions.

2. Determination of pH, alkalinity, and calcium hardness alone, using the aggressive index, are insufficient to judge whether or not A-C pipe will be attacked (softened) by a given water.

3. Substances such as iron and zinc in the water can provide considerable protection to A-C pipe by a mechanism not yet defined. With respect to zinc protection, Larson[9] has stated that

> Zinc in many natural waters containing alkalinity of 50 to 100 mg/L or more will form an insoluble protective coating of basic zinc carbonate in the pH range of 7.5-8.5 at room temperature or lower. In hot water tanks, there is evidence that zinc becomes cathodic to iron at temperatures above 140° to 160°F with certain types of waters. Traces of copper (0.1 mg/L) in the water can "plate out" on zinc or iron and result in pitting.





A-C coupon tests indicate that such substances as iron and zinc can provide considerable protection to A-C pipe by an undefined mechanism.

Because these tests and most distribution systems have temperatures at or below room temperatures, such a mechanism may be operating. The results of another zinc protection study were reported by Courchene and Kirmeyer,[10] who used zinc orthophosphate. They concluded that "Although the system was effective at reducing corrosion, the addition of phosphates to Seattle water demonstrates a potential to stimulate algae growth in open distribution reservoirs." Their findings suggest the need for study of other forms of zinc.

4. Calcium carbonate saturation can be used to prevent attack on A-C pipe. Regarding the calcium carbonate saturation index, Larson[9] observed that "Experience has shown that the greatest weakness in the saturation index occurs with waters of relatively low alkalinity and calcium." The A-C coupon in experiment 8 at the pH of calcium carbonate saturation (pH_s) may have been very slightly softened because the calcium concentration and alkalinity were low.

Comparison of asbestos fiber count data from systems A and J (Table 16) also demonstrates the influence of pH and calcium concentration on the release of fibers from approximately the same lengths of pipe. Although the source waters are similar in character, system J never had any corrective lime treatment applied. The lime treatment in system A afforded considerable protection to the A-C pipe, even if the treatment was not begun until after the pipe was already severely deteriorated in some sections of the distribution system.

Theoretical considerations. These laboratory tests showed the effects of zinc addition, pH adjustment, alkalinity and calcium, or combinations of these factors on whether A-C pipe can retain its surface hardness. To explain what was happening chemically in these experiments and to predict the action of other combinations of water quality factors, a survey of the solution chemistry of zinc in relation to A-C pipe coating was conducted. The computer program used permits multiple aqueous interactions to be evaluated. The computer survey produced graphs of the saturation index and of soluble zinc at equilibrium, which illustrate the final effect of the chemical interactions in the solutions. The results of this survey will be presented in a second article, where they will explain and support the laboratory coupon test results discussed in Table 15.

Protection and rehabilitation of existing systems. To determine whether methods

exist for protecting and rehabilitating A-C pipe, the DWRD has initiated two extramural research projects with utilities G and H. Utility G is adding zinc to the water to discover whether the amount of asbestos fibers released from A-C pipe that is slightly attacked is reduced. Utility H, which has badly deteriorated but still structurally sound pipe, proposes to use calcite coating[4,5] after the mains are cleaned.

Future Research

A partial list of future research questions to be investigated by A-C coupon tests and further field testing includes the following:

1. Will zinc provide protection at very low calcium concentrations?
2. Will zinc provide protection at lower zinc concentrations (0.1-0.2 mg/L)?
3. Will sodium silicate provide A-C pipe protection?
4. Will the protection processes that work for A-C pipe influence metal pipe?
5. What is the coating formed by iron or zinc on the A-C pipe? Mah and Boatman[7] have found by use of scanning electron microscopy that when zinc orthophosphate is used in A-C pipe experiments, zinc but not phosphate is found on the surface. They have not determined if the zinc is elemental or in a compound form.
6. Do any environmental impact problems occur with the use of zinc?
7. How do protection processes that work well experimentally perform in existing distribution systems? (This work has been started in system G.)
8. Can A-C pipe coupons be used for rehabilitation studies? Deteriorated A-C pipe is to be treated without special preparation, and also after the surface has been scraped clean of any loose and softened materials. The tests for both conditions are to be calcium carbonate saturation, zinc addition, and McCauley's process[4] for calcite coating of pipe as modified by Radziul.[5] This latter procedure will be tried in system H.
9. What other water quality factors influence the performance of A-C pipe? Research currently under way at system I, where water with a low aggressiveness index is not attacking A-C pipe, will help answer this question.

Conclusions

Although three extramural studies and one in-house project are still in progress, sufficient data have been collected to support the following conclusions:

1. Calculation of the aggressiveness index alone is not always sufficient to predict actual behavior of A-C pipe.
2. Collecting a single sample for an asbestos fiber count is often insufficient to judge the actual behavior of A-C pipe in a given situation.
3. Wet drilling and tapping of A-C pipe, if not performed with a flushing device on the tapping machine, can cause a major release of fibers.
4. Metals such as zinc, iron, or manganese in the water can change A-C pipe behavior.
5. Water is not expected to be attacking A-C pipe when the initial aggressiveness index is above about 11, the pH or the concentration of calcium do not change significantly as the water flows through the pipe, and no asbestos fibers are found consistently in representative water samples. When high asbestos fiber counts are found in representative water samples at one time, but not another, at a location where the water flow is sufficient to clean the pipe of tapping debris, the water probably is not attacking the A-C pipe. (Recent tapping can cause high fiber counts not related to pipe attack.) Similarly, when high asbestos fiber counts are found only in water samples collected from low-flow dead ends or from fire hydrants (nonrepresentative samples) and nowhere else in the system, the A-C pipe probably is not being attacked.
6. Water is likely to be attacking A-C pipe when the initial aggressive index is below 11, and the pH and the concentration of calcium as the water flows through the pipe increase significantly, and the water does not contain iron, manganese, or similar metals. (In system I iron in the water probably protected the pipe.) High asbestos fiber counts consistently found in representative water samples collected from locations where the flow is sufficient to clean the pipe of debris, and where drilling and tapping of the pipe has not been performed near or during the sampling period, indicate that the water is attacking the A-C pipe. That inlet water screens at coin-operated laundries become plugged with fibers is another indication.

Inspection of pipe sections removed from the ground is the best method of assessing the condition of asbestos cement pipe. If inspection is not possible, a review of the factors listed in (5) and (6), in addition to a determination of asbestos fiber counts by transmission electron microscopy (with repeated sampling if possible), will aid in determining the condition of the A-C pipe.

In summary, this study has demonstrated that asbestos-cement pipe behaves much like other piping materials, except PVC, that are commonly used for distribution of drinking water. If aggressive water conditions exist, the pipe will corrode and deteriorate; if aggressive water conditions do not exist, the pipe will not corrode and deteriorate.

A-C pipe has had a reputation for resisting attack by aggressive waters that cause corrosion of metal pipe materials. Tracey[11] said "It was often assumed that cement-asbestos pipe stabilized in one or two years of use..." A-C pipe also was installed because it did not produce rusty water problems. The results of this study better define the behavior of asbestos-cement pipe under a variety of water quality conditions.

Acknowledgments

The authors wish to thank the superintendents of the various water utilities participating in this study for their cooperation. They also wish to thank William Mueller for his assistance with the A-C coupon studies, James Agee and Lynn Peters for their help on the pipe loop experiment, Carl Shadix and Michael Schock for their analytical chemistry support, and Richard Feldman for some of the asbestos fiber counts.

References

1. AWWA Standard for Asbestos-Cement Distribution Pipe, 4 in. Through 16 in., for Water and Other Liquids. AWWA C400-77. AWWA, Denver, Colo. (1977).
2. McFarren, E.F.; Millette, J.R.; & Lishka, R.J. Asbestos Analysis by Electron Microscopy. Proc. WQTC, Denver, Colo. (1975).
3. Asbestos Analytical Methodology Committee Interim Method for Asbestos. USEPA, Envir. Res. Lab., Athens, Ga. (1976).
4. McCauley, R.F. Controlled Deposition of Protective Calcite Coatings in Water Mains. *Jour. AWWA*, 52:11:1386 (Nov. 1960).
5. Radziul, J.V. et al. A Liquid Cement-Calcite Pipe Coating Process. *Jour. AWWA*, 59:11:1413 (Nov. 1967).
6. Langelier, W.F. The Analytical Control of Anti-Corrosion Water Treatment. *Jour. AWWA*, 29:10:1500 (Oct. 1936).
7. Mah, M. & Boatman, E.S. Scanning and Transmission Electron Microscopy of New and Used Asbestos-Cement Pipe Utilized in the Distribution of Water. *Scanning Electron Microscopy*, 1:85 (1978).
8. Merrill, D.T. & Sanks, R.L. Corrosion Control by Deposition of CaCO Films: Part 2, A Practical Approach for Operators. *Jour. AWWA*, 69:12:634 (Dec. 1977).
9. Larson, T.E. Corrosion by Domestic Waters. Bulletin 59. Illinois State Water Survey, Urbana, Ill. (1975).
10. Courchene, J.E. & Kirmeyer, G.J. Seattle Internal Corrosion Control Plan—Summary Report. Proc. AWWA Ann. Conf., Atlantic City, N.J. (1978).
11. Tracey, E.L. Observations on Water Samples from Cement-Asbestos Pipe Systems in Vermont. *Jour. NEWWA*, 64:164 (Jun. 1950).

An annual conference paper selected by the JOURNAL, authored by Ralph W. Buelow (Active Member, AWWA), res. sanit. engr., James R. Millette (Active Member, AWWA), phys. sci., Earl F. McFarren, retired, and James M. Symons (Active Member, AWWA), chief, phys. and chem. contaminats removal branch, all of the USEPA, Cincinnati, Ohio.

77793 5535